Feasibility of Biodegradable MEMS based on Cellulose Paper

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ABSTRACT

This report deals with the micro-patterning process of EAPap (Electro-Active Paper) for fabricating biodegradable and flexible MEMS. EAPap has been known as an active material with an interesting actuation phenomenon of papers. Such active materials were made by depositing very thin electrodes on both sides of cellulose paper strip. When an electric field is applied to the paper strip, a large displacement was produced. This active material has merits in terms of large strain, low voltage, low power consumption, dryness, cheap and biodegradable nature. This material can be designed in such a way that its advantages can be optimized. With these advantages and possibility, this material is attractive for biodegradable and flexible MEMS. This report illustrates a micro-patterning process on flexible EAPap material. Key issues in this biodegradable MEMS fabrication with EAPap are 1) the preparation of EAPap material for micro scale fabrication, 2) micro patterning possibility on EAPap and 3) functional capabilities of sensing and actuation. The micro contact printing for the micro-patterning on the EAPap flexible membrane is developed and its feasibility for biodegradable MEMS fabrication is investigated.

Keywords: Electro-Active Papers (EAPap), Cellulose, Micro-fabrication, Micro transfer printing, Biodegradable and flexible MEMS

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1. INTRODUCTION

Electroactive polymers (EAP) have received much attention due to the development of new EAP materials that exhibit a large displacement output. This characteristic is a valuable attribute that has enabled a myriad of potential applications, and it has evolved to offer operational similarity to biological muscles. Some of the currently available materials are ionic polymer metal composites (IPMC), gel-polymers, conductive polymers, electric field activated EAPs such as electron irradiated P(VDF TrFE), electrostrictive polymer artificial muscle (EPAM), electrorheological fluids, EAPap, and so on [1-6]. The field of EAP is broad and offers enormous potential for many applications.

Electro-active paper (EAPap) has been incidentally discovered as an actuator material with an interesting actuation phenomenon of papers [7]. Such actuators were made by depositing very thin electrodes on both sides of cellulose paper strip. When an electric field is applied to the paper strip, a large displacement was produced [8]. EAPap material is attractive for artificial muscles due to its many advantages in terms of light-weight, large displacement, low activation voltage and low power consumption. The working principle of such a smart material is claimed to be piezoelectric effect and ionic migration effect at the same time associated with dipole moment of cellulose paper ingredients. This material can be designed in such a way that advantages of ionic EAP and electronic EAP can be optimized. Thus, this material has a lot of possibility that can meet the requirement for EAP as artificial muscles. With these advantages and possibility, this material is attractive for biodegradable and flexible MEMS. However, it is difficult to apply conventional micro-fabrication process, because of its flexibleness, low flatness, and hydrophilic nature. In this paper, micro-transfer printing (MTP) technology is studied for EAPap material and its validity for MEMS application is investigated. The MTP process consists of a master fabrication, PDMS stamp construction, and micro pattern transfer (Figure 1). Concept of the process is explained and the results are discussed.

2. EXPERIMENTAL

2.1 Fabrication of master

The master for manufacturing PDMS stamp was fabricated by using conventional lithograph technology. The master was made by trench etching on silicon wafer. It was used for making a micro structure on silicon wafer by using SU-8 photo resist, for the simplicity of process. The process begins by coating SU-8 having thickness of 50 μm on silicon wafer by using a spinner. The solvent included in SU-8 on wafer is evaporated by soft baking at 95℃. The cross linker of SU-8 was strengthened when it was exposed to UV (350-400 nm). After exposing, post baking was performed at 95℃ in an oven and the area of SU-8 unexposed to UV was removed by the developer (1-Methoxy-2-propanol acetate).

2.2 Manufacturing of PDMS Stamp

The PDMS stamp was made by Sylgard™184 PDMS (Polydimethylsiloxane; Dow Corning Co.). A 10:l (v:v) mixture of PDMS-Sylgard™184 silicone elastomer and curing agent were stirred for 30 min and remained in a vacuum chamber to remove air bubbles [9]. Extra silicon oil with a molecular weight 7000 was added to the mixture not more then 3WT% to reduce the adhesion of PDMS stamp [10,11]. After the mixture was poured onto the prepared master, the mixture was kept in the vacuum chamber again to securely form the stamp. The PDMS was cured at room temperature for 1h, and cured again at 65℃ for 1 h until the polymer was rigid [12]. Finally, The PDMS was cooled down to room temperature and it was carefully peeled off from the master.

2.3 Process of Micro contact printing

The MCP is a soft lithography method. It was applied to transfer a micro-patterning of gold electrode on a cellulose paper. The process for printing patterns on the surface of cellulose paper is composed of i) self-assembly monolayer (SAM) coating on the PDMS stamp, ii) gold deposition on the stamp, iii) stickable SAM coating on the cellulose paper, and iv) the contact process of the PDMS stamp and the cellulose paper.

A nonstickable SAM (Trichloro(perfluorooctyl)silane, Aldrich) was coated on the PDMS stamp to let the gold layer easily remove from the stamp. Gold layer was deposited by a thermal evaporation system (0.5mm/s, 10^{-7} torr) on the surface of PDMS stamp on which the nonstickable SAM was coated. The thickness of gold layer is about 100nm. A stickable SAM ((3-mercaptopropyl)trimethoxysilane, MPTMS, Fluka) was coated on the cellulose paper by putting them into a vacuum chamber for 3 hours (1 torr) at room temperature[11]. Finally, the cellulose was contacted with PDMS stamp for several seconds.

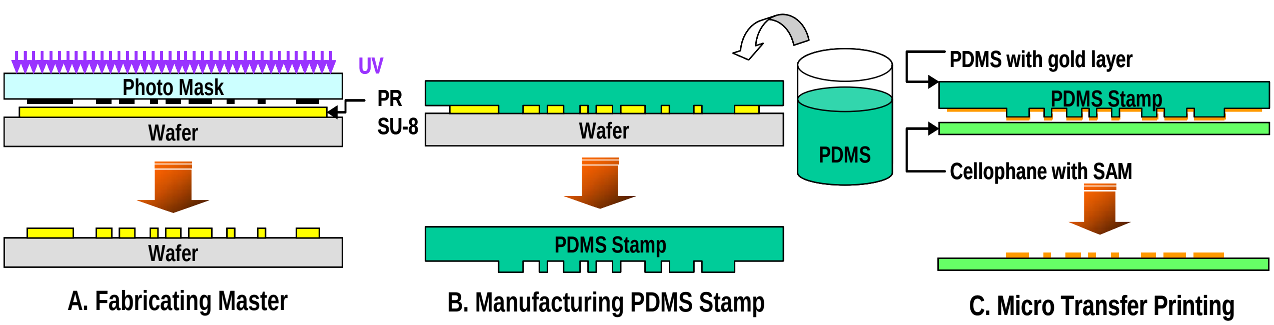


Figure 1. The process of micro transfer printing (MTP)

3. RESULTS AND DISICUSSION

3.1 Mechanism of micro contact printing

Figure 2 shows the mechanism of Micro contact printing process. Figure 2-A and B represent the formation of hydrogen bonds between hydroxyl groups of the cellulose paper and MPTMS SAM. When small amount of MPTMS was coated on the cellulose paper, it leads to co-condensation of the methoxy groups of the MPTMS with the hydroxyl groups on the surface of the cellulose paper [10]. For preparing of the step C, a nonstickable SAM was coated on the surface of PDMS stamp and a gold layer was coated on the surface of the stamp using the evaporator. The nonstickable SAM coating is made to transfer the gold layer easily to the cellulose paper. Figure 2-C shows that the PDMS stamp was contacted with SAM coated on the cellulose paper. The covalent bonding of the SAM "glue" to both the substrate and the gold can ensure a good adhesion of the printed gold pattern. Finally, the gold particles attached on PDMS stamp were transferred to the SAM coated cellulose paper after a few seconds contacting.

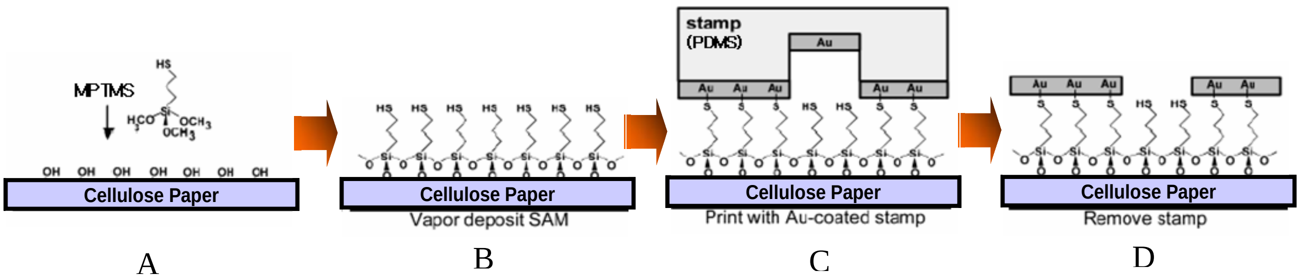


Figure 2. Mechanism of micro transfer printing on the cellulose paper

3.2 Micro transfer printing of IDT and dipole antenna pattern on cellulose paper

To test the micro-patterning possibility on cellulose paper, two patterns were tried to make: Interdigital Transducer (IDT) for surface acoustic wave (SAM) device, and dipole rectenna (rectifying antenna) for microwave power transmission. Figure 3-A shows an optical microscope image of the PDMS stamp for an IDT pattern of SAW sensor. Figure 3-B is magnified view of showing well-formed IDT pattern of PDMS stamp. The distance between the units of IDT is 6.6μm. Figure 3-C and D show the SEM images of gold layer coated on the PDMS stamp. They represent a good step coverage of the deposited gold layer on PDMS stamp. Figure 3-E is the SEM image of the IDT gold pattern transferred on the cellulose paper. Figure 3-F is the enlarged view of it. It shows a successful formation of qualified gold electrode pattern on the cellulose paper. We confirmed that the prepared micro pattern can act as electrode for EAPap through measured surface resistance, 0.284 Ω/mm^2.

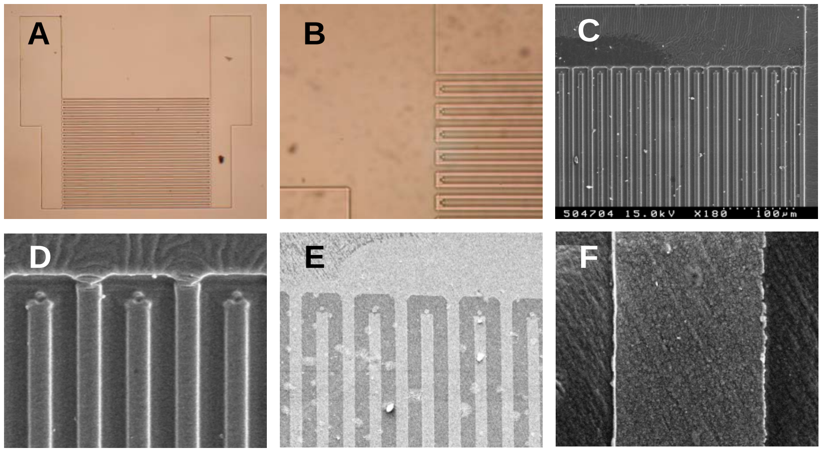
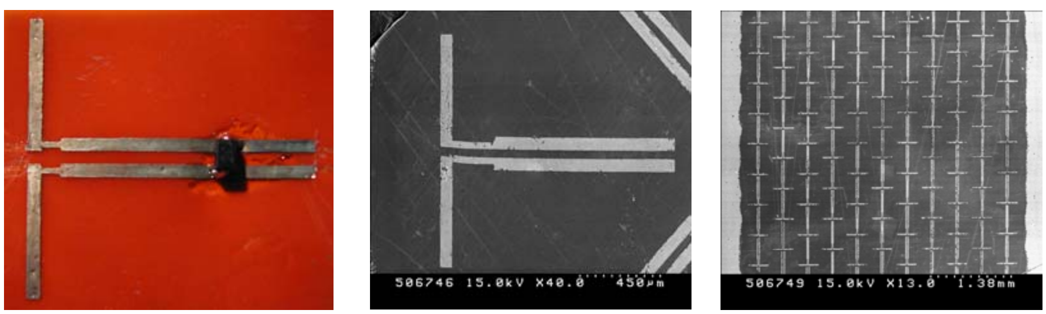


Figure 3. Gold patterns on cellulose paper using Micro transfer printing

Figure 4-A represents a dipole rectenna element designed for 10 GHz. Dipole rectenna is a combination of an antenna and a rectifier consisting of dipole metallic strips, a Schottky barrier diode, inductor, and a capacitor, which converts microwave power into a DC power. The rectenna was fabricated using FPC (Flexible Printed Circuit board) and schottky diode. The MTP process was tried to realize the rectenna pattern, having higher frequency range, on cellulose paper. Figure 4-B and 4-C show the image of printed dipole antenna and its array on the surface of the cellulose paper. This dipole antenna was designed for 75 GHz, at which the dipole length is 1mm.



A B C

Figure 4. Photos of dipole rectenna: A) dipole rectenna sample, B) unit dipole rectenna pattern fabricated by MTP and C) dipole rectenna array

4. SUMMARY

In this paper, we investigated the possibility of micro transfer printing technology as an efficient method for the micro-fabrication of MEMS device using EAPap material. For the MTP technology, master fabrication, PDMS stamp fabrication, SAM coating, gold layer deposition, and the contact printing were successfully performed. As results, IDT pattern for a SAW device and dipole rectenna pattern were made on cellulose papers. The MTP process still has problems of adhesion control using SAM and contact force control. Nevertheless this method is promising for the micro-patterning of biodegradable and flexible MEMS, like EAPap materials.

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